Probabilistic seismic risk assessment of "Placa" buildings: Selection of Building Stock Geometry and Properties

Author: Vasco Bernardo (vbernardo@lnec.pt)

Supervisors: Paulo Candeias (LNEC) and Aníbal Costa (University of Aveiro, Portugal)

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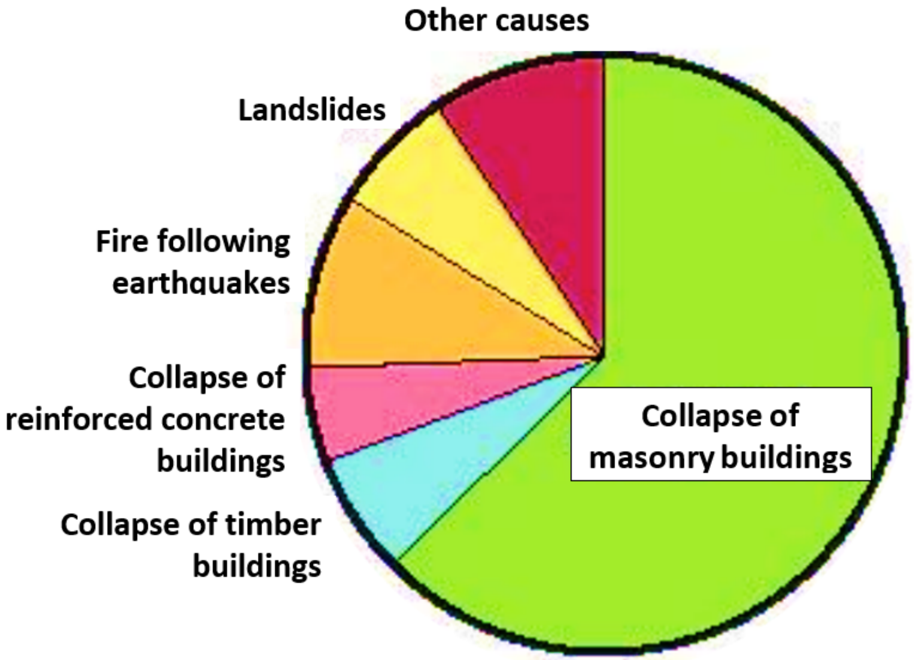
Motivation

- High number of collapses;
- Save and protect human lives;
- Reduce the impacts and losses;
- Conservation of built heritage.



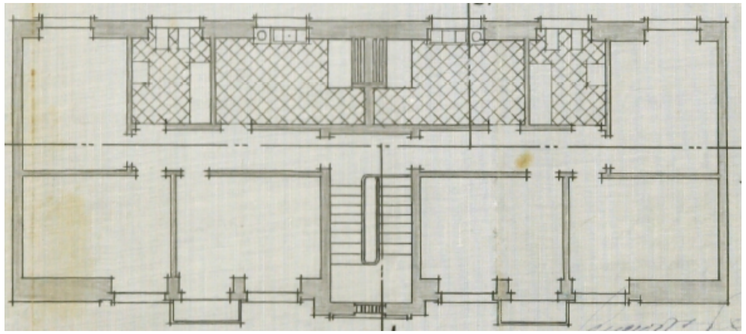
Earthquake fatalities by cause (1900-1992) Coburn & Spence, 2002

Targets

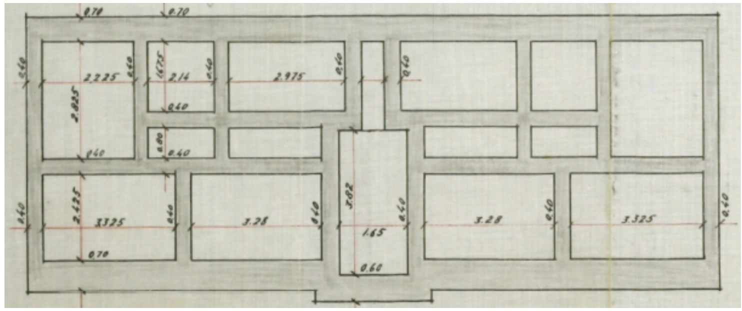
- Seismic risk assessment of “Placa” buildings in Metropolitan Area of Lisbon (MAL);
- Understanding and predicting local and global failure mechanisms;
- Define strategies for seismic risk mitigation based in cost-effectiveness analysis.

The “Placa” Buildings Typology

- Period of construction: ~1930-1960;
- Slabs in RC and simply supported on masonry walls;
- Exterior walls with clay solid bricks or stone masonry;
- Interior walls with hollow clay bricks;
- Regular plans and up to 5 stories high.



Typical floor plan

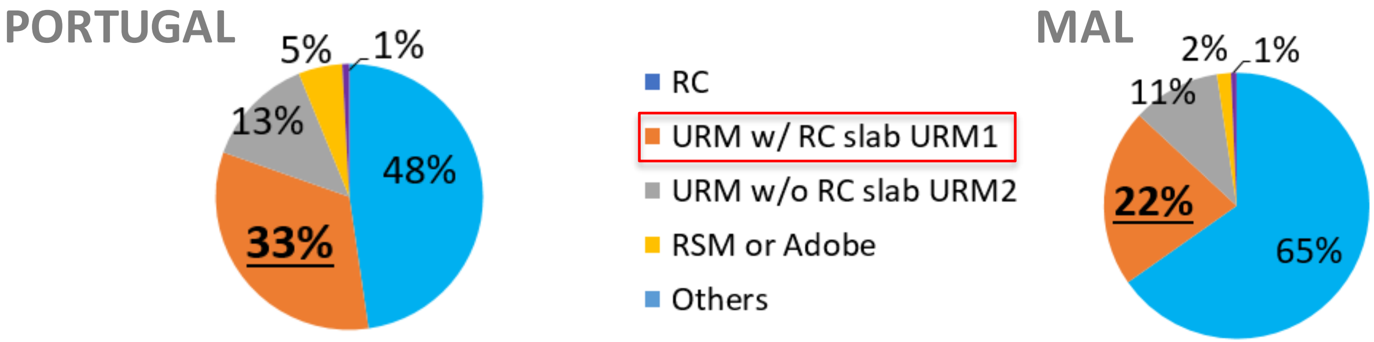


Foundations

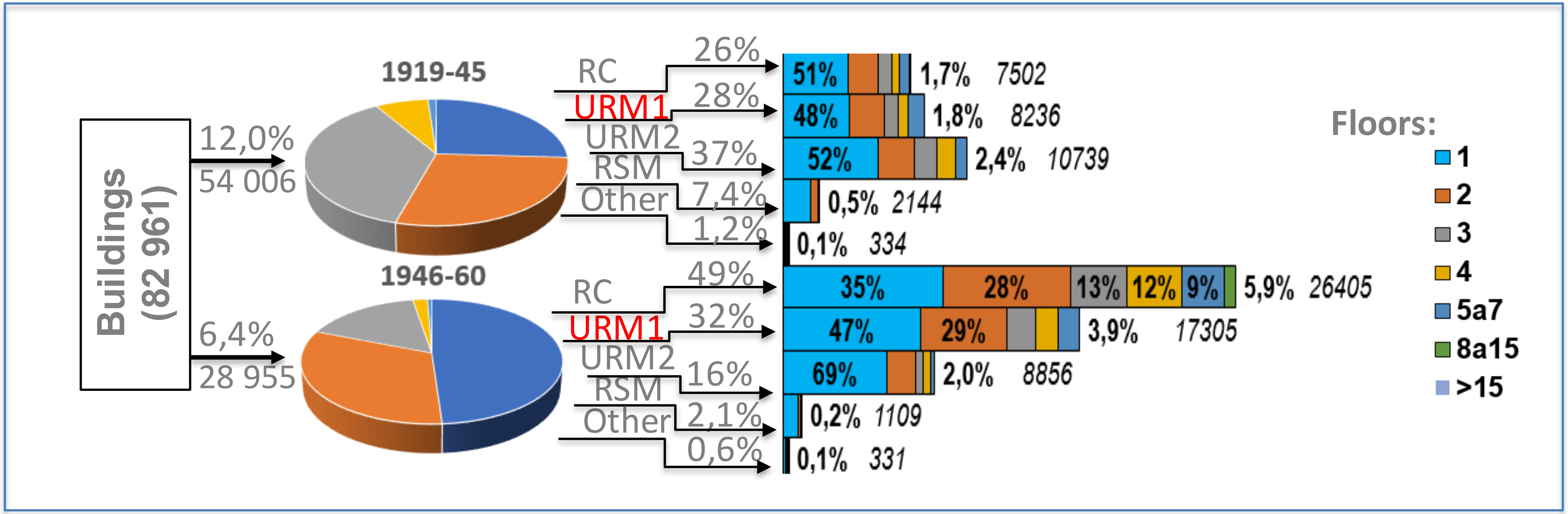
Weak Points

- “Placa” buildings are a pre-code seismic design typology;
- Vertical structural elements with low resistance to shear and bending;
- Very heavy structure;
- Unseating and collapse of the floor… pounding on adjacent buildings…;
- Inadequate human intervention (openings or removed walls, addition of floors…).

Global Statistics of “Placa” buildings – MAL (Census 2011)



Disaggregation of Census 2011 Data for Buildings – M.A.L.



Lisbon and Tagus Valey – 90% of “Placa” buildings have up to 4 stories high

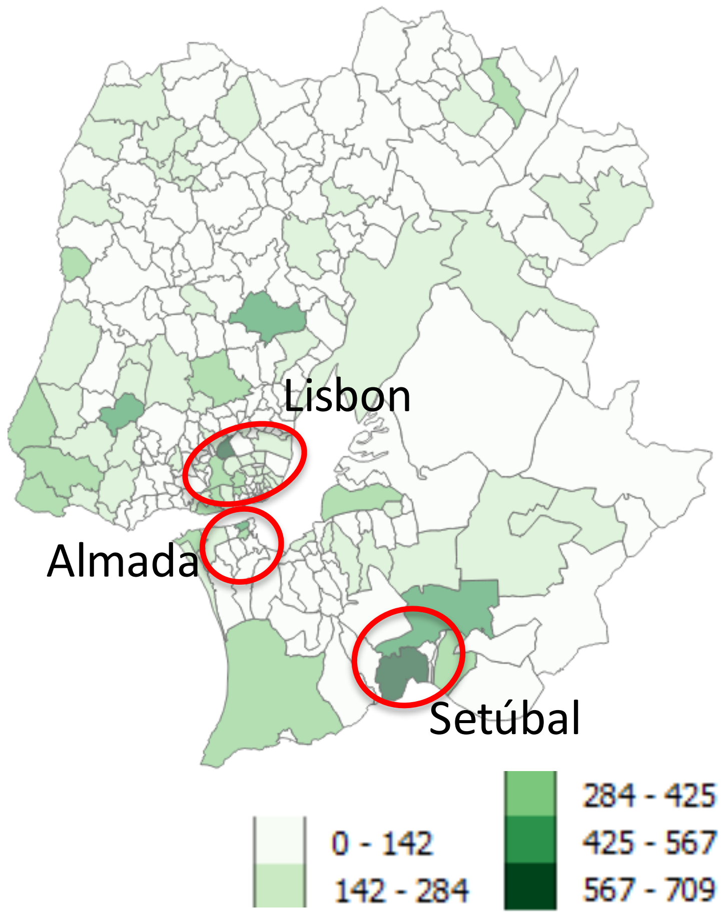
Geometry Buildings Selection

Statistical Analysis of “Placa” Building Geometry

➢ Geometric characterization to define the representative “Placa” buildings in MAL:

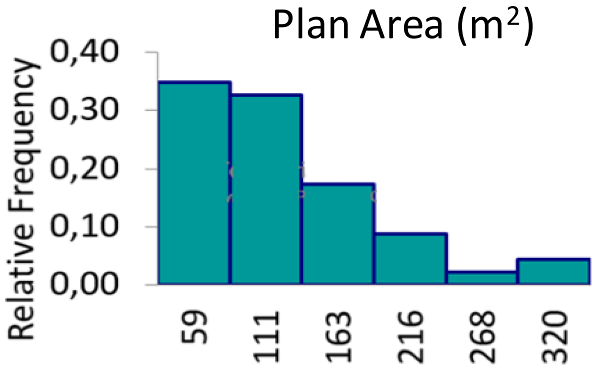
- Number of floors;
- Plan dimensions and building elevation;
- Number of partitions (to estimate the interior walls extension);
- Wall thickness;
- Openings (number of doors /windows and size);
- Spandrels and piers dimensions;
- Slab thickness;
- Constructive and design details (materials, foundations, loads…)

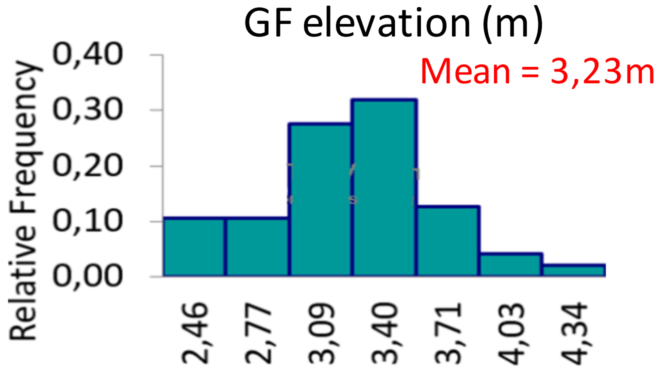
Selection of building stock

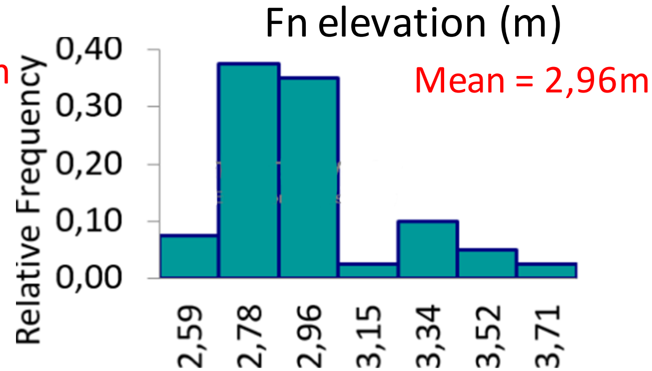


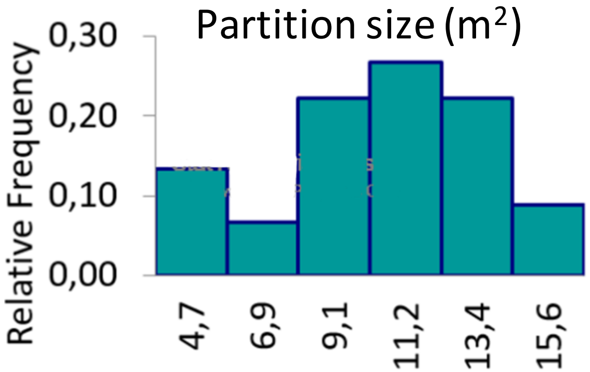
Statistical Analysis of “Placa” Building Geometry

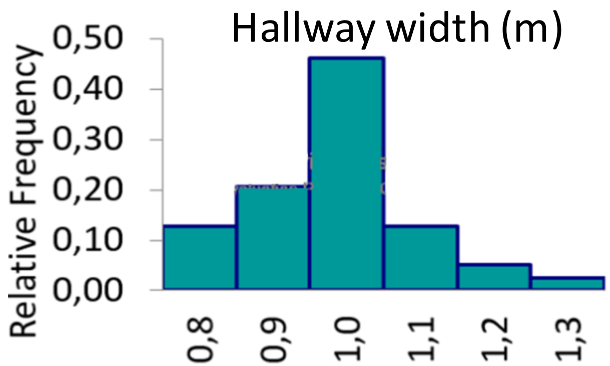
- Resume of main geometry:

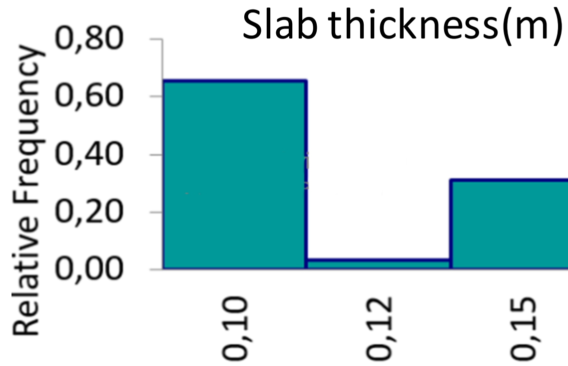


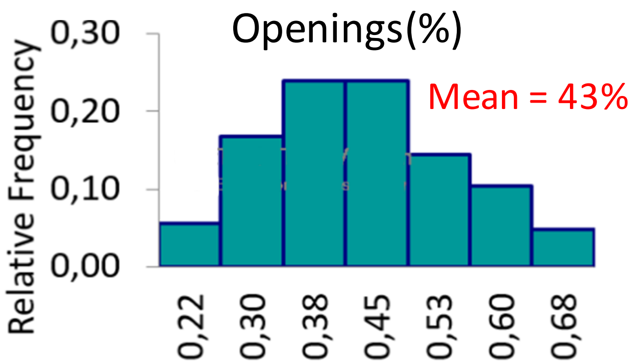










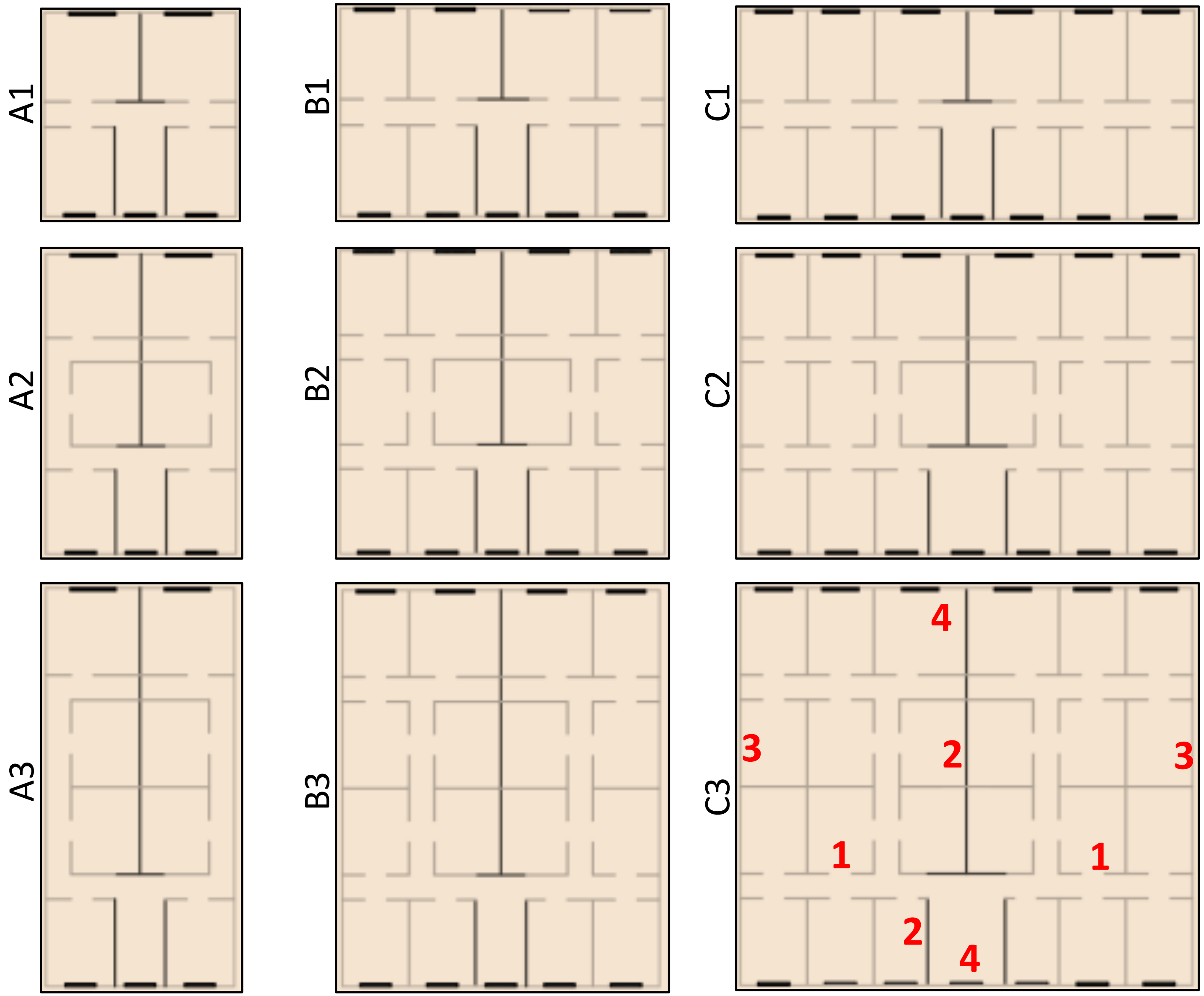


Mean wall thickness(m)

Wall	Floor			
	1	2	3	4 and 5
Partition	0,11	0,11	0,11	0,11
Interior	0,20	0,21	0,20	0,20
Common	0,32	0,31	0,29	0,29
Facade	0,48	0,47	0,42	0,42

Statistical Analysis of “Placa” Building Geometry

- Defined **9 plans** to represent the building stock geometry



Type	Size (m)	Area (m^2)
A1	7.5x8.0	60.0
A2	7.5x12.5	93.8
A3	7.5x16.0	120.0
B1	12.5x8.0	100.0
B2	12.5x12.5	156.3
B3	12.5x16.0	200.0
C1	17.5x8.0	140.0
C2	17.5x12.5	218.8
C3	17.5x16.0	280

1 – Partition walls
2 – Interior walls
3 – Side walls
4 – Facade walls

Material Properties Definition

Analysis of “Placa” Building Properties

- **Masonry wall:**

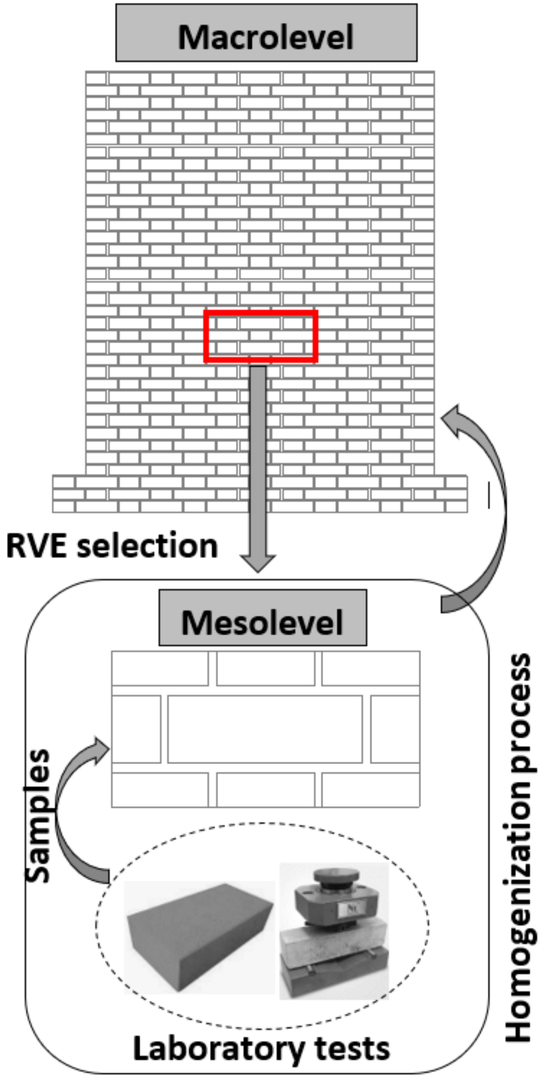
  1. Brick and mortar properties obtained by experimental tests on lab (LNEC – Ana Marques PhD Thesis);
  2. Homogenized Properties using FEM orthotropic model (research work carried out during my stay in Prague);
  3. Validation with experimental cyclic test (LNEC);
  4. Monte Carlo simulation to consider uncertainty in ***E, G, ϒ, fc, c, μ.***

- **Concrete Slab:**

  - Deterministic properties (rigid floor).

Analysis of "Placa" Building Properties

- Effective elastic properties from homogenization:



Brick and mortar properties

Material	E [GPa]	ν [-]	ft [MPa]	Gft [N/m]	fc [MPa]	ρ [kN/m^3]
Brick	13.0	0.2	2.0	58.0	40.0	18.0
Mortar	0.7	0.2	0.1	10.0	1.30	17.5

1st Order Homogenization using FEM (for prescribed strain ***E***):

$$\Delta \boldsymbol{u}(\mathbf{x}) = \Delta \boldsymbol{E}\,\mathbf{x} + \Delta \boldsymbol{u}^*(\mathbf{x}) \qquad \Delta \boldsymbol{u}^*(\mathbf{x}) = \mathbf{N}(\mathbf{x})\Delta \boldsymbol{r}$$

$$\Delta \boldsymbol{\epsilon}(\mathbf{x}) = \Delta \boldsymbol{E} + \Delta \boldsymbol{\epsilon}^*(\mathbf{x}) \qquad \Delta \boldsymbol{\epsilon}^*(\mathbf{x}) = \mathbf{B}(\mathbf{x})\Delta \boldsymbol{r}$$

Average of virtual work done by local stress and strain fields:

$$\langle \delta \boldsymbol{\epsilon}^{\mathrm{T}}(\mathbf{x}) \Delta \boldsymbol{\sigma}(\mathbf{x}) \rangle = 0 \qquad \mathbf{K}\Delta \boldsymbol{r} = \Delta \boldsymbol{f}$$

$$\mathbf{K} = \frac{1}{\Omega}\int_{\Omega} \mathrm{B}^{\mathrm{T}}(\mathrm{x})\mathbf{L}(\mathrm{x})\mathrm{B}(\mathrm{x})\, \mathrm{d}\Omega \qquad \Delta \boldsymbol{f} = \frac{1}{\Omega}\int_{\Omega} \mathrm{B}^{\mathrm{T}}(\mathrm{x})\mathbf{L}(\mathrm{x})\Delta \boldsymbol{E}\, \mathrm{d}\Omega$$

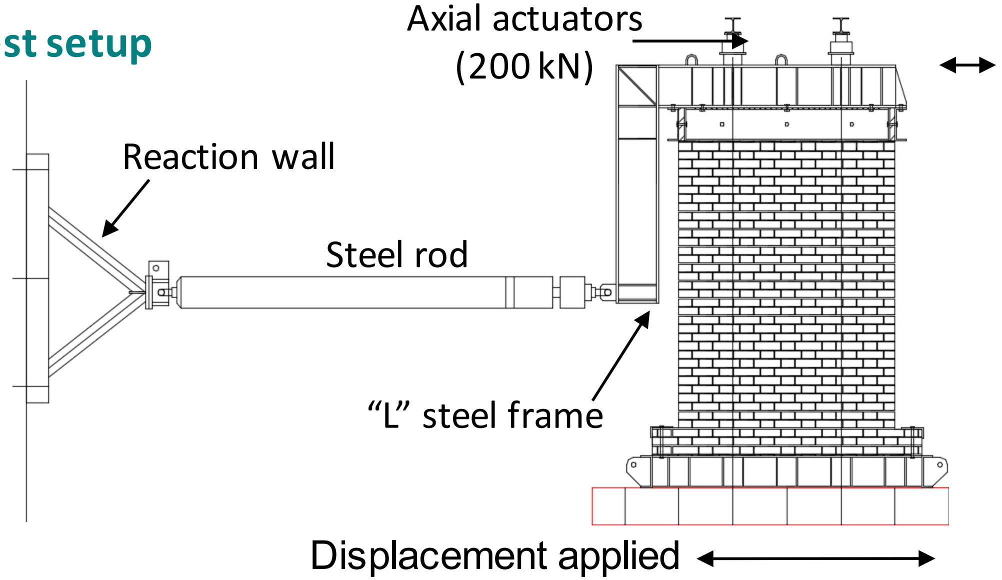
Equivalent elastic properties

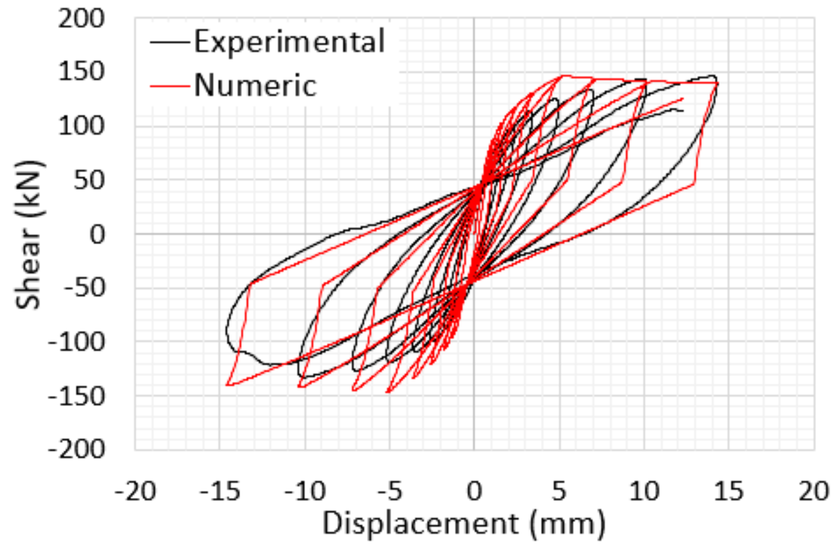
$E11$ $[GPa]$	$E22$ $[GPa]$	$G12$ $[GPa]$	$\nu12$ $[-]$	$\nu21$ $[-]$
6.68	4.03	0.67	0.089	0.147

Analysis of “Placa” Building Properties

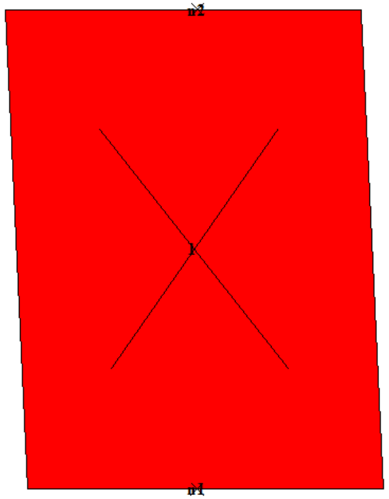
- Calibration and validation of macroelement on Tremuri with cyclic experimental test:

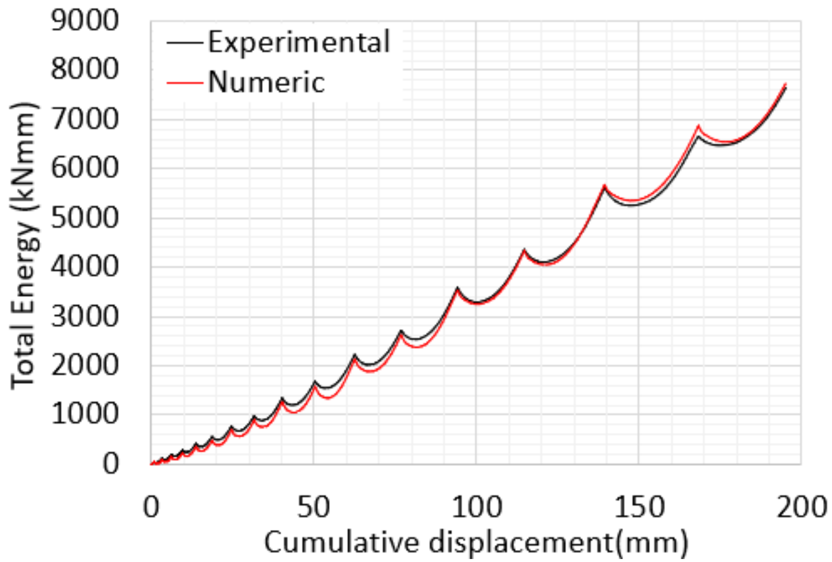
Test setup





Damage pattern





Analysis of "Placa" Building Properties

- Analysis of uncertainty in masonry properties - ***E, G, ϒ, f_c, c, μ.***
  - *Monte Carlo* simulation *(100 samples).*
  - Error ~ 5% for samples generated with a C.I. = 95%

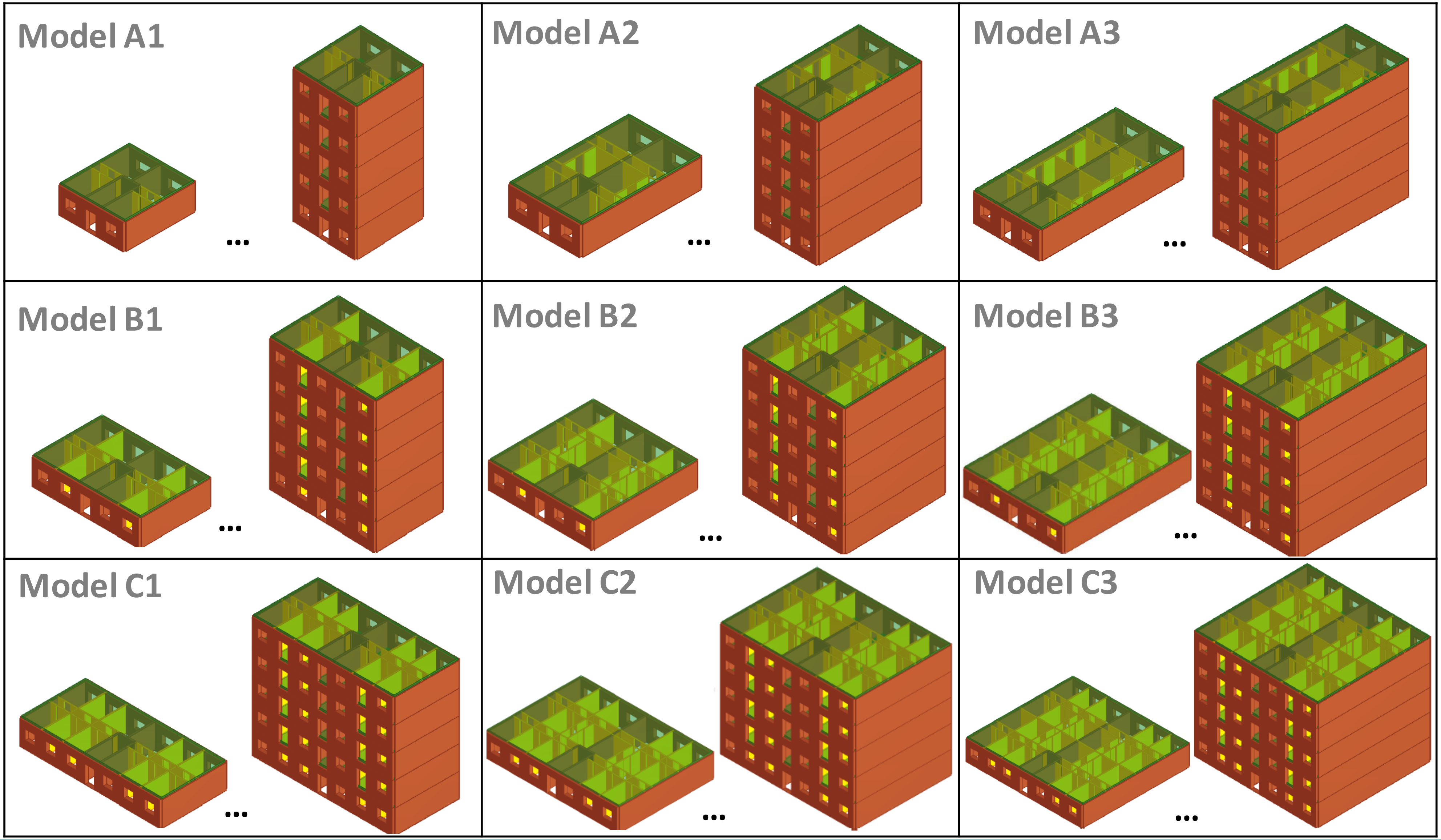
Correlated by **K** factor (E, G, ϒ, Factor K, Fc)

Variable	Masonry (solid clay bricks)		Masonry (hollow clay bricks)		Distribution
	mean	COV	mean	COV	
E [GPa]	4,50	0,25	1,50	0,25	LogNormal
G [GPa]	1,80	0,29	0,65	0,29	LogNormal
ϒ [kN/m³]	18,0	0,05	12,0	0,05	Normal
Factor K [-]	800 (250 - 1100)	0,25	700 (250 - 1100)	0,25	Truncated Normal
Fc [MPa]	5.40	0,17	2,10	0,17	LogNormal
c [MPa]	0,20	0,40	0,20	0,4	LogNormal
μ [-]	0,15	0,19	0,15	0,19	LogNormal

Numerical Analysis

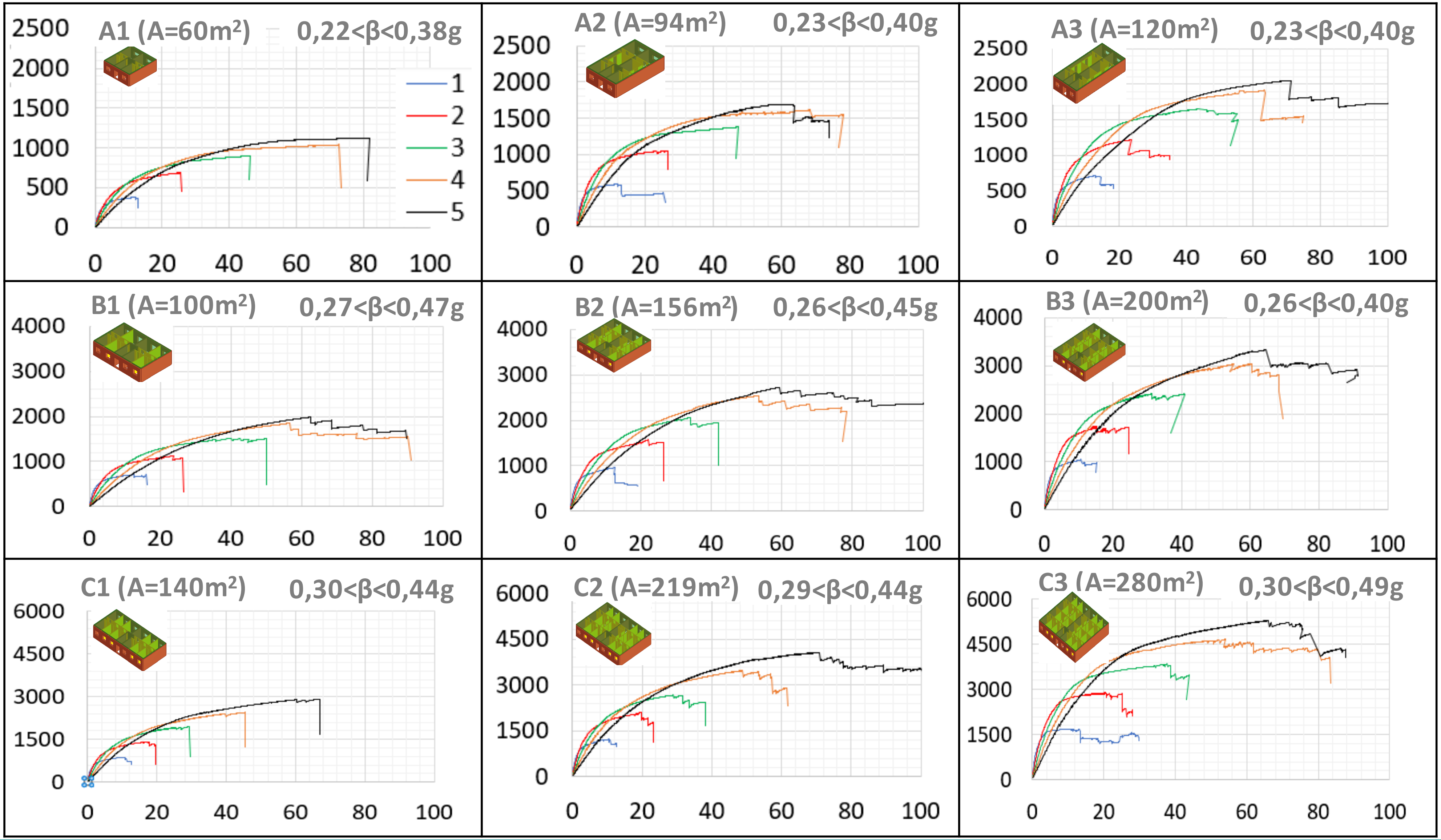
Numerical Analysis for “Placa” Buildings

Built **45 numerical models** (9 plans x 1 to 5 floors) for represent the building stock.



Numerical Analysis for “Placa” Buildings – Capacity curves

➢ Capacity curves (X direction) for **median properties** - base shear (kN) x displ (mm):

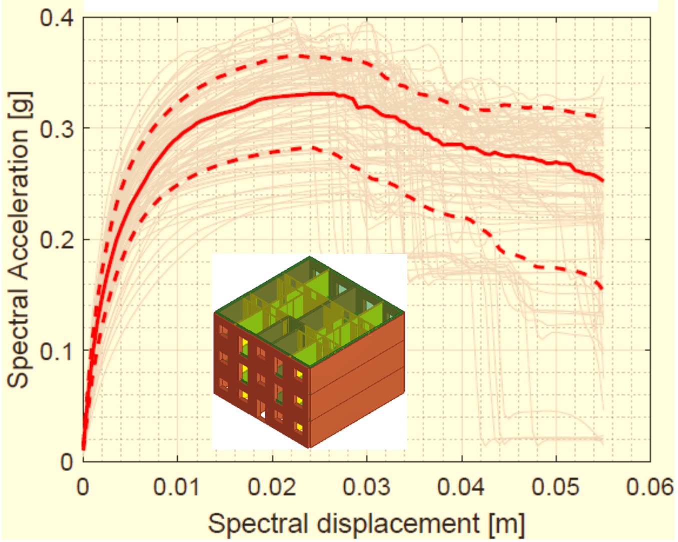


Numerical Analysis for “Placa” Buildings – Fragility curves

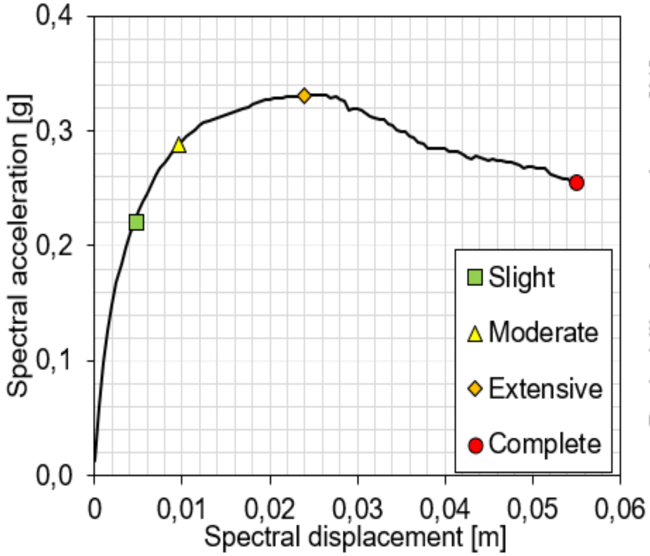
- Fragility curve defined by lognormal functions that describe the probability of reaching, or exceeding, a defined limit state;
- Performed 100 pushover analysis in X direction;
- Preliminary fragility curves applied to model **B2 (3 floors);**
- Limit state (HAZUS) defined as interstory drift;

Threshold of damage state	Drift [%] (HAZUS)
Slight	0,16
Moderate	0,32
Extensive	0,80
Complete	1,87

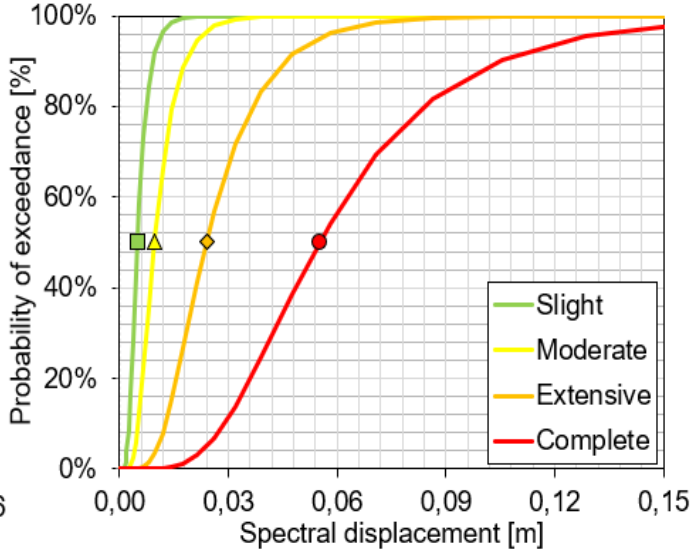
Capacity Spectrum in X direction



Median Curve

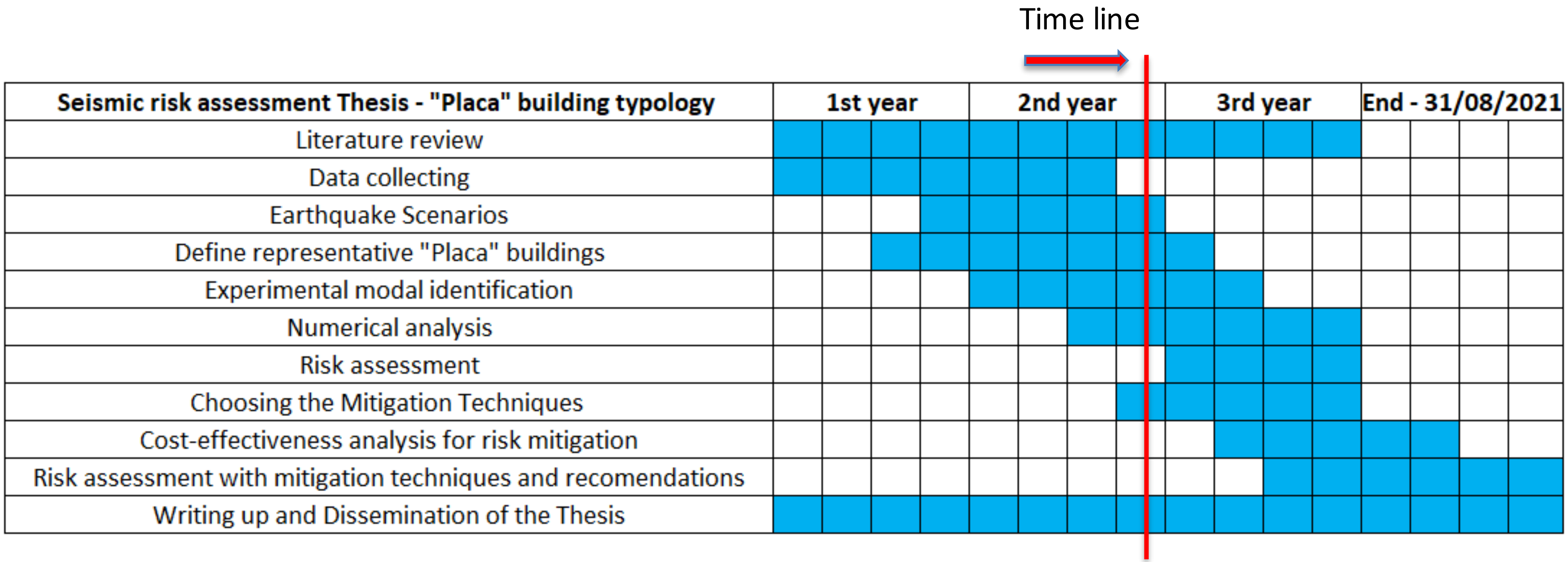


Fragility curves



Final comments and Research Plan

- Pushover analysis in X / Y direction: 100 samples x 45 buildings **(around 9000 analyses)**;
- Define Performance point for different return periods;
- Define limit states based on macroelement damage parameter;
- Fragility curves for buildings defined.
- Establish relations between wall area and seismic coefficient;



Publications

- *"Análise não linear de um conjunto de edifícios em "placa" no bairro de Alvalade: avaliação preliminar de estabilidade e previsão dos mecanismos de colapso"*, Vasco Bernardo, Paulo Candeias, A. Campos Costa e Aníbal Costa, Sísmica 2019 - 11º CONGRESSO NACIONAL DE SISMOLOGIA E ENGENHARIA SÍSMICA, IST, Lisboa, 29 e 30 de abril de 2019.

- *"Comportamento de paredes de Alvenaria sujeitas a ações no plano: Análise numérica e validação experimental"*, Vasco Bernardo, Ana Marques, Paulo Candeias, Alfredo Campos Costa and João Ferreira, Sísmica 2019 - 11º CONGRESSO NACIONAL DE SISMOLOGIA E ENGENHARIA SÍSMICA, IST, Lisboa, 29 e 30 de abril de 2019.

- *"Homogenization of unreinforced old masonry wall comparison of scalar isotropic and orthotropic damage models"*, Vasco Bernardo, Tomas Kerujci, Tomas Kudelka, Michal Sejnoha, The 10th annual conference of Nano and macro mechanics 2019, CTU, Prague.

THANK YOU

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